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UTILIZATION OF A NEGATIVE FEEDBACK CIRCUIT

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/Figures appended/

The negative feedback circuit, as one of the new methods of increasing the efficiency, quality, and stability of the operation of much electrical equipment, has received wide dissemination in present communications techniques.

The negative feedback circuit occupied a particularly steady place in the field of low frequency amplifiers, due to the possibility of considerably decreasing the nonlinear distortions and, consequently, obtaining higher power with the same tubes in the output stages.

How does this decrease of nonlinear distortions take place?

The feedback circuit provides at the input of the equipment, in reverse phase, a certain portion of the output voltage, comprised of the useful signal and harmonics. Then, the part of the useful signal supplied from the output in reverse to the input, decreases the initial effective useful signal at the input of the apparatus, and the part fed to the input comprised of harmonics appears again, after amplification, at the output, but in phase opposition, and diminishes the initial effective value of the harmonics.

From this it is evident that due to the feedback circuit, at the output of the apparatus both the harmonics and the useful signal are decreased proportionally. However, the useful signal can be restored to the previous level by increasing the voltage of the source of the signal at the input of the apparatus. Then, at the output, the useful signal voltage will be of the required intensity, while the harmonics will be decreased by the amount that the amplification of the equipment is decreased through action of the feedback circuit. In this lies the basic idea for obtaining the advantages of using the negative feedback circuit.

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Let us examine an amplifier design with a voltage feedback circuit, and see how the charge of the amplification decreases when the feedback circuit is connected.

In Figure 1 we see that the voltage at the input of the amplifier U_g is a geometric sum of the voltage of the signal source U_{go}, and the voltage of the feedback circuit, taken from the voltage divider at the output of the amplifier, βU_a, i.e.,

$$U_g = U_{go} + \beta U_a;$$

hence, the coefficient of amplification of the apparatus with the presence of the feedback circuit is

$$k' = \frac{k}{1-k\beta},$$

where k is the coefficient of amplification of the apparatus without feedback circuit, defined as

$$k = \frac{U_a}{U_g};\ \beta = \frac{R_1}{R_1+R_2}.$$

The obtained equation is the basic one of an amplifier with a feedback circuit, with the help of which the necessary computations can be made.

Insofar as the coefficient β is negative, the amplification of the apparatus decreases $(1+k\beta)$ times. Evidently the maximum value of β is equal to unity. The value $k\beta$ is called the feedback factor and shows what portion of the resulting input signal is comprised of the feedback voltage.

We shall show, in a numerical example, how the harmonics in an amplifier diminish when a feedback circuit is utilized.

Let us say that it is necessary to decrease the nonlinear distortion (harmonics) in the amplifier, for example, 51-fold. The normal output voltage of the amplifier is 100 v with an input voltage of one v. The amplitude characteristic of the amplifier is such that with a voltage at the input of one v, the voltage of the harmonics at the output amounts to 10. These data describe the amplifier without the feedback circuit. Now we shall connect a feedback circuit to the amplifier, taking β equals 0.5. With this, the amplification of the apparatus decreases $(1+\beta k)$ times, i.e., $(1+0.5 \times 100)$ equals 51 times. The amplification falls because the portion β of the output signal is fed to the input in phase-opposition decreasing the useful signal at the input.

The output signal now consists of: $\frac{100}{(1+0.5 \times 100)}$ equals $\frac{100}{51}$ v and the β part equals $0.5 \times 100/51$ equals $50/51$ volts. $50/51$ v is diminished by the voltage of the negative feedback circuit and only $1/51$ v comprises the effective voltage of the oscillation on the input terminals of the amplifier.

Let us say that with an oscillation of one v we happened to be operating right on the top bend of the amplitude characteristic. With this, the harmonics comprise 10 v or 10 percent in relation to the output signal of 100 v. With an oscillation of $1/51$ v, we are operating on a rectilinear portion of the amplitude characteristic and the harmonics comprise in all only 0.0002 v, or one percent, instead of 10 percent with an oscillation of 10 v.

Due to the action of the feedback circuit, these harmonics decrease 51-fold, giving a total of only 0.000004 v at the output. But we need a normal output of 100 v which can be obtained if the effective voltage at the input is one v and not $1/51$ v.

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What value of the source voltage of the input signal is needed in order that the effective voltage should be one? Evidently 51 v, because with the feedback factor $k\beta$ equals 50, 50 v will be extinguished by the feedback voltage and the effective voltage on the input terminals of the amplifier will be one v. The nonlinear distortion of 10 v stipulated for this value of oscillation will be decreased 51-fold because of the action of the feedback circuit, and will consequently be $10/51 \cong 0.2$ v. The output voltage will be a nominal 100 v.

Thus, the decrease of the nonlinear distortion was achieved at a cost of increase of the source voltage of the input signal.

After this numerical example, we shall again turn to the coefficient of the feedback circuit β and examine certain other of its qualitative characteristics.

In the case of multistage amplifiers, it is easy to obtain $k\beta \gg 1$. Disregarding the one in the denominator in this case we receive

$$k' = \frac{1}{\beta},$$

i.e., with sufficiently strong feedback the amplification does not depend upon the parameters of the amplifier circuit and tubes, but depends only upon the attenuation of the feedback circuit. If β is made independent of the frequency, then the amplifier will have ideally flat frequency characteristics. Actually, amplifiers with feedback circuits have a flatter frequency characteristic than amplifiers without feedback circuits. On the other hand, if β is made dependent upon frequency, according to the law we require, then this permits us to correct the frequency characteristic in any given direction. It must also be noted that insofar as $k\beta$ appears in general as a complex value, then for certain frequencies (usually at the extremities of the band of operation) the amplifier can pass into a state of regeneration, i.e., in this case the negative feedback circuit transforms itself into a positive one. This requires the adoption of suitable measures, chiefly in multistage amplifiers.

Feedback circuits are differentiated by the method used in forming the feedback voltage. The feedback voltage can be proportional either to output voltage, or current in the output circuit, or dependent upon one or the other.

As an illustration we shall examine the circuits of amplifiers with voltage and current feedback, as shown in Figures 2a and 2b.

As is shown in Figure 2a, the feedback voltage is taken from the voltage divider $(R_1 + R_2)$ which is connected in parallel with the primary winding of the output transformer. Condenser "C" is necessary for isolating the plate voltage supply from the grid circuit.

The feedback coefficient is determined by the relationship $\frac{R_1}{R_1 + R_2}$. With the connection of the voltage divider to the primary winding of the output transformer, there still remains an interference on the load, caused by the pulsation of the plate voltage supply. By connecting the divider in parallel with the secondary winding of the output transformer, the interference voltage also decreases $(1 + k\beta)$ times. In the second case the need for the isolating condenser "C" ceases.

An amplifier circuit with a current feedback circuit, shown in Figure 2b, is simpler. The feedback voltage is taken from the resistance R, connected into the cathode circuit. This voltage is proportional to the current flowing through the load and not to the voltage of the load, as in the previous case. In this circuit there occurs a stabilization of the load current, just as the first plan stabilizes the load voltage. Therefore, wherever a condition of constant load voltage is required, voltage feedback is applied; and wherever a condition of constant current is needed, current feedback is employed.

Current feedback is rarely applied in amplifiers because it does not improve the frequency characteristic. The current feedback circuit can be applied in amplifiers through resistances, with subsequent correction for the obstruction of the frequency characteristics at the lower and higher frequencies.

The current feedback circuit is used in RF and IF in the amplifier stages of receivers and is easily realized by using a bias resistor without a blocking condenser. The application of current feedback makes the selectivity curves of receivers more stable. In regard to the final stages of receivers, which ordinarily drive dynamic speakers, only voltage feedback is applicable since it makes possible the maintenance of constant voltage on the speakers, independent of changes in the impedance of the voice coil, within fairly wide limits.

Therefore, in the majority of the receivers produced, at present the final stages of amplifiers are stabilized by voltage feedback.

However, in both the examined cases the decrease of the nonlinear distortion is attained at the expense of a decrease in the amplification of the apparatus.

The question arises as to whether it is possible to place at the input of the apparatus only a component of the harmonics, separated from the output voltage in such a way that the feedback circuit would not decrease the amplification of the apparatus.

Such designs have been created and are called feedback balancing circuits. One of our well-known designers of balancing circuits, G. S. Tsykin, effectively used a feedback balancing circuit in a "power stage" unit. In series with the feedback voltage, a certain value of signal voltage is applied to the balancing circuit in order to neutralize the useful signal component in the feedback circuit.

The remaining harmonic component, after it is applied to the input of the amplifier in phase-opposition, is amplified and balances out the harmonic present in the output circuit.

Figure 3 shows an example of a power amplifier with a balancing feedback circuit.

In series with the signal voltage taken off Transformer T_1, the feedback voltage forms across resistance R and appears as the difference between the voltage taken from the secondary winding of transformer T_2 and the output voltage taken from the supplementary winding of the output transformer.

Then at the resistance R, only the component of the harmonics of the output voltage will be formed. Insofar as the voltage on the auxiliary transformer T_2 fully balances itself to the component of the useful signal of the feedback voltage, transformer T_2 operates without a load.

Balancing circuits are much more complicated than simple feedback circuits, and they sometimes need an auxiliary amplifier to amplify the compensation voltage appearing as the difference between the input and the output voltage.

Feedback balancing circuits found an application in power amplifiers operating usually in a push-pull circuit as a Class B amplifier with grid currents.

The application of feedback balancing circuits has permitted the transfer of amplifier VUO-500 out of Class A into Class B; as a result, its power tripled while preserving the same degree of fidelity.

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The industrial efficiency increased from 12 to 38 percent and the tubes in the output stage were decreased from four to two.

This example oldarly indicates the great possibilities for the use of feed-back circuits.

[Appended figures follow]

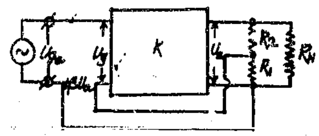
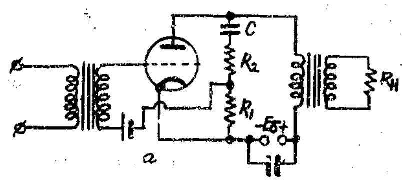


Figure 1

Figure 2a



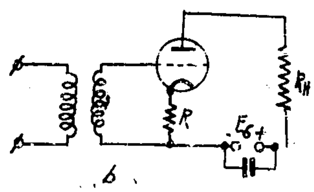
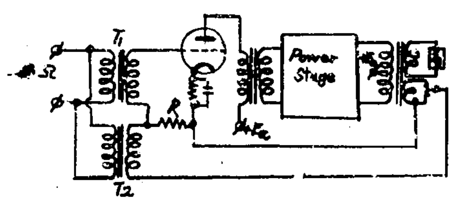


Figure 2b

Figure 3



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